MONITORING NEEDS TO MEET BENTHIC TMDL REQUIREMENTS

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Biographical Sketch of Authors

Ms. Jane Walker joined the Virginia Water Resources Research Center in 1999 as a research associate, where she works on various projects concerning watershed management and drinking water supply. Ms. Walker is a graduate of James Madison University (biology) and earned a M.S. degree in environmental sciences from the University of Virginia. She is the project coordinator for six benthic TMDL projects in Virginia. Ms. Kimberly Porter is a research assistant at the Virginia Water Resources Research Center at Virginia Tech. Ms. Porter, an environmental science major assisted with field measurements and data analysis for the TMDL report presented in this article. Dr. Tamim Younos is a senior research scientist and associate director at the Virginia Water Resources Research Center at Virginia Tech. His educational background is in Civil and Environmental Engineering (doctoral degree, the University of Tokyo) with research and teaching interests in watershed management, environmental hydrology, and water and waste management in rural environments. Currently he is involved in the development of six benthic TMDL reports for impaired stream segments in Virginia. Dr. Younos has authored more than 100 research/technical publications on water resources and water quality management issues.

Abstract

Benthic impairments--waters that do not support the aquatic life use--are based on the interpretation of narrative criteria. The impairment designation is based on the bioassessment of the benthic macroinvertebrate community in the impaired segment compared to a reference condition. A visual assessment of the impaired segment is needed to determine the possible impacts to the stream, and physical and chemical water monitoring is suggested to determine the impacts of background contributions. The anthropogenic stressors that may have caused the impairment include both point and nonpoint sources of pollution and can be estimated through diligent monitoring. However, because of the costs associated with water sampling and analysis, determining the number of samples, the sample location sites, and the types of analyses needed to estimate the pollutant loads becomes critical. Proper monitoring is required to understand the effects on the benthic community during critical stream conditions and during normal seasonal variations. The margin of safety factor required for the TMDL calculation should consider scientific reasoning and uncertainty analysis to interpret monitoring results. The authors of this article, based on their experience, have developed procedures for efficient and cost-effective development of TMDL reports for benthic impairments that take into consideration both point and nonpoint stressors and other factors such as the impact of fish predators on benthic organisms. The utilized monitoring plan, which incorporated suggestions from stakeholders, was well received during TMDL public meetings.

Introduction

In Virginia, all state, surface waters have a designated use to support aquatic life. The water quality criteria utilized to protect this designated use is a general narrative statement: "All state waters, including wetlands, shall be free from substances … which interfere directly or indirectly with designated uses…or which are harmful to human, animal, plant, or aquatic life." Currently 111 stream segments (455 miles) in Virginia are designated impaired and included in its 303(d) list for not adequately supporting aquatic life. A water body placed on the 303(d) list must establish a total maximum daily load (TMDL), an estimate of all significant sources of a pollutant and the specific amount of the pollutant coming from each source.

Bioassessments are used to describe the aquatic life condition of a surface waterbody. State agency scientists have used bioassessments to implement mandates of the Clean Water Act since its inception in 1972 (Barbour & Burton 2002). The Virginia Department of Environmental Quality (DEQ) uses surveys of benthic macroinvertebrates—the insect larvae, crustaceans, snails, mussels, clams, worms, leeches, etc. that live on the bottom of waterbodies—to determine if the aquatic life use is being met. The results of benthic macroinvertebrate surveys from the stream in question are compared to an undisturbed regional reference condition. For 303(d) listing purposes, the minimally impacted reference site, which was originally chosen for scientific purposes to represent a pristine condition, has unintentionally defaulted to the water quality standard.

The community of benthic macroinvertebrates in a waterbody is affected by the habitat structure, water quality, and other environmental factors (e.g. Hellawell 1986, Younos & Walker 2002). Factors that negatively impact the benthic community population and diversity are called **stressors**. The TMDL studies are only needed for streams with benthic impairments owing to anthropogenic effects so it is important to distinguish between natural and anthropogenic stressors. Natural stressors include but are not limited to high winds, low and high rainfall, frost action, snowfall and intense sunshine. Major anthropogenic stressors are:

- hydraulic alterations
- sediment load
- organic load
- chemical (e.g., heavy metals and pesticides) loads
- changes in pH
- changes in water temperature
- predation or competition by introduced species

The objective of this paper is to describe the process and data requirements to develop benthic TMDL reports. Two streams with benthic impairments are used as examples. The approaches and protocols used for the bioassessment, stream corridor assessment, and characterization of the trout farm effluents and nonpoint source load allocations utilized in the TMDL reports are described.

Approaches for Benthic TMDL Reports

The authors propose the 10 steps outlined below to address benthic impairments. A full TMDL report is to be developed only if Steps 1 and 2 below indicate impairment.

1. Check the validity of the reference condition. Is the impaired segment compatible with the reference condition in terms of water source (water chemistry) and other characteristics as defined under the regional reference condition? If the original biosurvey did not use a compatible reference condition, the status of the impairment should be reevaluated using a compatible reference condition.
2. Most stream segments are designated as impaired using the RBPII protocol. Reevaluate each impaired segment using the RBPIII protocol. If the RBPIII method reconfirms the status as impaired, proceed with developing the TMDL report. Consequently, because the taxonomic identification of the RBPIII method is performed at the genus level, it may serve as an indicator of the stressors or pollutant sources.
3. Obtain stakeholder input early and throughout the process.

4. Establish a relationship between benthic macroinvertebrates and their predators. For example, many fish are predators of benthic organisms, and their presence may contribute to lower or different populations of benthics in the stream.
5. Conduct a comprehensive stream corridor survey for the riparian zone and landuse assessment for both the impaired segment and the reference condition watershed.
6. Initiate water sampling and analysis for both the impaired segment and the reference condition (NPDES permit data may not be adequate). Water sampling regime and parameter coverage should be consistent with variability regime and parameters of suspected stressors.
7. Identify stressors for both the impaired segment and the reference condition using published literature, data from Steps 3, 5 and 6.
8. Compute stressor loads (point and nonpoint sources) for both the impaired segment and the reference condition. The riparian zone should be considered as the critical zone in terms of nonpoint source contribution.
9. Make recommendations to reduce pollutants loads in the impaired segment to equivalent or lower loads found in the target condition.
10. Make recommendations for pollutant load allocations and management practices that could achieve the objective of Step 8.

Case Study Sites

Based on benthic macroinvertebrate surveys using Rapid Biological Assessment Protocol II (RBP II), the Virginia DEQ included six stream segments in the Year 1998 303(d) impaired waters list. These stream segments are located immediately below the discharge point of aquaculture facilities (trout farms). The processes for developing TMDL reports for two of impaired stream segments (Orndorff Spring Branch and Lacey Spring Branch) are presented in this report as case studies.

Orndorff Spring Branch is located in the Central Appalachian Ridge within the Shenandoah Valley, Virginia. The stream is a first-order stream with two perennial springs as headwaters (flow ≈ 2.1 cfs). The impaired segment, 0.15 miles in length, begins at the outfall of a trout facility, and continues to the confluence with Cedar Creek. The effluent from the trout facility was suspected as the cause of the impairment, but the exact pollutant or pollution causing the impairment was not identified (DEQ 1998). The land use of the Orndorff Spring Branch watershed (8 acres) is mixed forests (69%), deciduous forests (16%), roadways (14%), and cropland (1%). The reference stream for the impairment designation is Ingleside Springs Branch, which is located in the same Valley ecoregion (limestone subregion). The land use for the Ingleside Springs Branch watershed (50 acres) consists of pastureland (99%) and a road (1%). An analysis of water chemistry for total dissolved solids, alkalinity and hardness indicated that the water chemistry for Orndorff Spring Branch and its reference stream, Ingleside Springs Branch are compatible.

Lacey Spring Branch is also located in the Central Appalachian Ridge and Valley ecoregion and limestone subregion. The stream is a first-order stream with a perennial spring as the headwater (flow ≈ 7.2 cfs). The impaired segment begins at the discharge of a trout farm and continues downstream for 0.2 miles to the confluence with Smith Creek. The trout farm effluent was suspected as the cause of the impairment, but the exact pollutant or pollution causing the impairment was not identified (DEQ 1998). The land use of the Lacey Spring Branch watershed (335 acres) consists of pastureland (58%), residential (28%), roadways (9%), and mixed forest (5%). The reference stream for the impairment designation is Mount Solon Spring Branch, which is located in the same ecoregion. The land use of the Lacey Spring Branch watershed (220 acres) consists of pastureland (58%), residential (28%), roadways (9%), and mixed forest (5%). An analysis of water chemistry for total dissolved solids, alkalinity and hardness indicated that the water chemistry for Lacey Spring Branch and its reference stream, Mt Solon Spring Branch were not compatible.

Methods

Verify the Benthic Impairment
The original benthic surveys for impairment designation were conducted in 1996. Benthic macroinvertebrate surveys were repeated using a combination of quantitative sampling and RBP III methodology. The quantitative sampling includes a series of replicate samples at each station, with five samples per sampling site, to allow for statistical analysis. A Hess Stream Bottom Sampler was used and standard sampling field and laboratory procedures as described by Barbour et al. (1999) were followed. The RBP III method, which identifies organisms to the genus/species level, was used because family level sampling (as utilized in the RBP II method) does not provide enough information to allow a critical analysis of the stream conditions. Additionally, the results of the RBP III analysis are likely to serve as a better indicator of the potential stressors and pollutant sources.

Stream Corridor Assessment
The stream corridor assessment procedure developed by the Maryland Department of Natural Resources (Yetman 2000) was modified for application to the TMDL project. A stream corridor assessment is a rapid walkthrough along the stream documenting any and all possible outside influences, both natural and man made. The upper and lower boundaries of the designated stream segment being surveyed were recorded with a global positioning system (GPS). A visual scan of the stream was performed, noting any entering ditches, excessive trash, foam or sheen on the water, eroded streambanks, channel alterations, exposed pipes, pipe outfalls, fish barriers, inadequate vegetation buffer, in/near stream construction, etc. Within the streambed, the survey accounts for the relative amounts of sand, silt, clay, cobbles, boulders, and bedrock; the embeddedness of the rocks; and the type of algae. The general landuse upstream of the stream segment was also noted as industrial, agricultural, residential, etc.

Land Use Assessments
The watershed boundaries for the impaired segments and reference streams were delineated by the PrePro system developed by the Center for Research in Water Resources (CRWR) at the University of Texas (http://www.ce.utexas.edu/prof/olivera/prepro/prepro.htm). The ArcView-based system uses digital elevation models (DEMs) and existing stream channel data to develop drainage networks and their corresponding drainage areas. Soils and land use data were clipped to the watershed boundary. Land use data were verified and updated based on field observations and information from property owners. Literature indicates that stream water quality is more critically affected by the conditions of the riparian zone (Davies and Nelson 1994, Tufford et al., 1998). Canopy vegetation within the riparian zone can affect sedimentation and water temperature in the stream. In this project, the riparian zone (a 300-ft buffer on each side of stream) was delineated for topography and land use characteristics. The data were used to estimate nonpoint source sediment loads to the streams.

Fish Population Surveys
Because some fish are predators of benthic macroinvertebrates, a high number of these fish (e.g., trout) in the stream may be responsible for lowering the macroinvertebrate numbers or changing the species composition of macroinvertebrates in the stream and thereby affecting the RBP analysis. The fish population surveys follow the procedure outlined by Barbour et al. (1999). The survey entails sampling with a pulsed backpack electroshocker in the in the same locations as the macroinvertebrate sampling, including in the reference streams for comparison purposes. The fish are identified to species, and their number and condition are recorded. The data were used to estimate the impact on benthic macroinvertebrates from the fish populations to see if there is a difference between the reference sites and the impaired streams.

Water Sampling and Analysis
Fish feeding, fish harvesting, and settling basin cleaning operations disturb the settled solid wastes and change the effluent characteristics. Likewise, the different amounts of feed provided throughout the year, as required to meet the changing needs of the fish, influence the characteristics of the effluent. The load of the effluent increases with higher amounts of feed put into in the system. Also, different facilities use different types of fish feed, which affect the effluent because some feeds have higher residual content than others. Intensive, yearlong monitoring of each facility is needed to have a better grasp of the pollutant loads, but year-round and continuous monitoring of

small aquaculture facilities is not practical and is cost prohibitive. Therefore, limited intensive monitoring was performed, and the results were extrapolated to determine total loads, which were then be compared to the target water quality conditions.

Stressor Identification
The process outlined in the EPA's *Stressor Identification Guidance Document* (EPA 2000) was used in the identification of critical stressors for the TMDL reports in this study. A list of candidate causes was developed from the benthic macroinvertebrate survey reports, published literature, visual surveys, and stakeholder input. Chemical analyses of collected water samples provided additional evidence to support or eliminate the potential candidate causes. From this information, the probable stressors and their probable sources were identified. An advisory panel, composed of experts in the field, weighed the evidence, eliminated some stressors from consideration, and identified the most probable stressors based on their best professional judgment. Once the stresses were identified, the next step was to identify the sources causing the stress.

Load Calculations
Point source loads for trout farm effluents were calculated using pollutant concentrations and stream flow rates. Stream flow rates were calculated from measured average velocities and measured stream cross-sectional areas. Nonpoint source loads for riparian areas were calculated using the Revised Universal Soil Loss Equation (RUSLE).

Results: The TMDL Report

Results in this report are organized in accordance to the 10-step-approach described earlier.

1. Check the validity of reference condition
Ingleside Spring Branch was used as the benthic reference stream for Orndorff Spring Branch in the initial DEQ impairment listing and was used to set the target condition in the TMDL calculations because the water chemistries for the two stream were compatible. Mount Solon Spring Branch was used as the benthic reference stream for Lacey Spring Branch in the initial DEQ impairment listing but its water chemistry was found to be incompatible with the reference stream Mount Solon Spring Branch. Furthermore, using the sediment load to Mount Solon Spring Branch as the endpoint target did not offer an attainable TMDL for Lacey Spring Branch even after eliminating all point sources and nonpoint sources. Therefore, Ingleside Spring Branch was used as the reference and TMDL endpoint target. The water chemistry of Lacey Spring Branch is similar to Ingleside Spring Branch, and the physical features (land cover condition and relatively shallow slopes) of its riparian area are similar to those for the Ingleside Spring Branch. A viable benthic community is attained at Ingleside Spring Branch and a viable benthic community should therefore be possible for the impaired sites if the stressor is reduced below the level in Ingleside Spring Branch.

2. Reevaluate the status of the impairment
Bioassessment of impaired segments conducted in 2001 reconfirmed the impairment designation for both impaired segments and therefore full TMDL reports were developed for both segments.

3. Obtain stakeholder input
Stakeholder input was received throughout the project. Stakeholders shared available data on facility operation and other relevant information, responded to a written survey, and participated in two public meetings. Stakeholder information and concerns were incorporated in the TMDL report to the extent possible.

4. Establish a relationship between benthic macroinvertebrates and their predators
A fish survey was conducted for the Lacey Spring Branch TMDL where escaped fish were observed below the trout farm effluent. Only a single species of fish, introduced rainbow trout, was collected. The relatively low abundance of trout (5.3 fish per minute) made it unlikely that fish predation could bias significantly the RBP

assessments. Based on these findings, it was concluded that fish predation is unlikely to be a stressor in the stream.

5. Conduct a comprehensive stream corridor survey

The stream corridor survey indicated that the point source load from the trout farm effluent was the only significant contribution to the impaired segment of the Orndorff Spring Branch. For the Lacey Spring Branch, point source pollutants from the trout farm effluent as well as pollutants originating from nonpoint sources contributed to the impaired segment. Two pastures, a grassy field, roads, and residential areas contributed to the nonpoint source loads.

6. Initiate water sampling/analysis and flow measurements

Water samples were collected from the reference sites, within each of the impaired streams, and from the effluent of the trout farms. Water samples were analyzed for alkalinity, hardness, total suspended solids, total settleable solids, total dissolved solids, dissolved organic carbon, ammonia-nitrogen, nitrate-nitrogen, nitrite-nitrogen, total Kjeldahl nitrogen (TKN), filtered TKN (dissolved TKN), total phosphorus (TP), filtered TP (dissolved TP), and ortho-phosphate. Water samples were collected from the springs (headwaters), the beginning of the benthic impairments, any entering tributaries, and the end of the benthic impairments. A Hydrolab Datasonde 4 was used to measure water temperature (C^o) and dissolved oxygen levels (mg/L) every 15 minutes over the course of one or two days in the impaired stream segments. Flow velocities were measured using a Global Flow Probe EP101.

7. Identify stressors

Based on the initial evidence provided, the following possible stressors were identified: ammonia, excess nutrients, organic enrichment, low dissolved oxygen levels, increased solids, toxic chemicals, hydraulic alterations, changes in pH, increased water temperatures, and fish predation.

Eliminated Stressors

Ammonia

An EPA update of ambient water-quality criteria for ammonia ranked genus mean acute toxicity values and found rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) to be more sensitive to ammonia than the studied macroinvertebrates (e.g., caddisfly, isopod, mayfly, amphipod, tubificid worms, and stonefly) (EPA 1999). Ammonia was present in some samples taken from the headwaters, most samples from the trout farm effluents, and within some samples from the impaired streams. The two farms presented as case studies had low total ammonia concentrations (0.00 - 0.76 mg/L), which were well below the chronic ammonia criteria for freshwaters in Virginia for the respective pH of the water. Ammonia toxicity was therefore eliminated as a critical stressor in Lacey Spring Branch and Orndorff Spring Branch.

Dissolved Oxygen, pH, and Temperature

According to Virginia water quality standards, the pH range for stream waters is to be between 6.0-9.0, a target which was met for both streams. The minimum requirement for dissolved oxygen is 4.0 mg/L. A minimum of 5.0 mg/L and 5.6 mg/L were recorded for Orndorff Spring Branch and Lacey Spring Branch, respectively. The daily average requirement for dissolved oxygen is 5.0 mg/L. The daily average recorded at both streams was 6.0 mg/L. The maximum requirement for temperature is $31C^o$. The maximum temperature recorded at Orndorff Spring Branch and Lacey Spring Branch were $19.3\ C^o$ and $13.6\ C^o$, respectively. All measured dissolved oxygen, pH, and maximum temperatures within the impaired segments met the numerical criteria for their water classifications, thereby eliminating these parameters as critical stressors.

Possible Stressors

Toxic Chemicals

Chemical additions to surface waters from industrial, urban, residential, and agricultural sources can be toxic to benthic macroinvertebrates. The impaired stream segments presented in this case study receive no runoff from industrial or urban sources. Residential sources of significant chemical contributions are unlikely because the few residential homes along the impaired streams would probably only offer occasional, low-concentration inputs of toxic chemicals. Because there is no significant crop production in the watersheds of the impaired streams, impaired streams are unlikely to receive significant amounts of pesticides in surface runoff. Herbicides may occasionally be applied to control thistles and other weeds in the pasturelands but are unlikely to cause the long-term observed effects. The use of salt and various fish therapeutics, including medicated feeds were reported for trout production. Because of the high densities of organisms found in the impaired streams, toxic chemicals were not believed to be critical stressors.

Excess Nutrients

Excess nutrients from both point and nonpoint sources were considered as likely stressors. Observations of increased biomass of periphyton and macrophytes below the trout farm outfalls in comparison to the rest of the stream and in relation to the reference streams indicate that excess nutrients may be coming from the trout facilities. Furthermore, at Lacey Spring Branch livestock have access to portions of the stream causing nonpoint source nutrient contributions. Excessive amounts of nutrients, nitrogen (N) and phosphorus (P), significantly increase the growth of algae, fungi, and rooted aquatic vegetation. Extreme increases in periphyton and macrophyte biomass can increase the demand for oxygen and thereby reduce the amount of oxygen available to the macroinvertebrates and negatively impact them. Laboratory data indicated that a large portion of the total Kjeldahl nitrogen (TKN, the organic forms of nitrogen and ammonia) in the trout effluent and the impaired waters were sediment bound. The total phosphorus (TP, organic and inorganic forms) was almost 100 percent sediment bound. It was concluded that management activities to control the solids would also control the excess nutrients reaching the impaired streams and thus the TMDL would focus on reducing solids.

Critical Stressors

Organic Solids

Solids in general have multiple effects on the benthic macroinvertebrate community. Solids can interfere with the respiration of benthic macroinvertebrates. Deposited solids that fill the interstitial spaces of the substrate reduce the available habitat for some macroinvertebrate species. Solids in water reduce the photosynthesis capabilities of aquatic plants, which are the food source for some benthic macroinvertebrates, and may clog the feeding nets of other benthic macroinvertebrates. Solids reduce the visibility in the water and can thus lower the success rate of predatory macroinvertebrates in capturing prey. Deposited organic sludge can also form a blanket over the substrate and result in the loss of interstitial organisms. It was concluded that not only is the load of the solids important but the type of solids is also important in developing a TMDL report.

The organic component of the solids was identified as the primary stressor to the impaired streams. This conclusion was based on literature information, types of benthic macroinvertebrates found (tolerant to organic pollution) in the impaired segments, and measured organic matter content in settling basins of study trout farms. Solids, which were found to be on average 60 percent organic (volatile solids), were observed in settling areas within the trout facilities in depths up to 14 inches. Solids originating from aquaculture facilities are primarily uneaten fish feed and fish wastes so are therefore highly organic in nature. Westerman et al. (1993) found solids in trout raceways and sediment traps to be about 77 percent organic and solids from settling basins to be 61 percent organic. Boardman et al. (1998) found the organic content of sludge from a trout farm in Virginia to range from 44 to 63 percent, with an average of 56 percent.

In summary, organic solids were identified as the critical stressor based on 1) the benthic monitoring results in the impaired segments, 2) a literature review of the effects of organic solids on benthic macroinvertebrate communities, 3) visual observations of accumulated solids in the trout farm raceways and the listed stream segments, and 4) data collected for the TMDL report.

8. Compute stressor loads

The load of organic solids attributed to the natural background and point sources were determined from measurements of total suspended solids and an estimated organic content. For the spring waters (representing the natural background levels), a five percent organic content was used, and for the point sources (trout farm effluents), an organic content of 60 percent was used in the TMDL calculations. Sediment load, as calculated from the Revised Universal Soil Loss Equation (RUSLE), and estimated organic content (five percent) were used to describe the nonpoint source organic solids contributions. The soils for the areas under study are naturally 2.5 percent organic (from soil surveys), but an organic content higher than this was used in the TMDL calculations for the nonpoint sources to account for contributions from runoff containing organic matter picked up on the surface (e.g., manure). The 5 percent organic content was also used in the load calculations for the spring waters because organic solids from the springs in this study most likely originate from nonpoint source runoff.

9. Make recommendations to reduce pollutant loads in the impaired segments

Because Virginia does not have a criterion for organic solids, the load of organic solids in the reference stream (Ingleside Spring Branch) was estimated and used to set the endpoint. The endpoint was calculated by estimating the organic solid load to Ingleside Spring Branch. Only nonpoint sources of pollution were identified in Ingleside Spring Branch. Therefore, a total solids load was estimated using the RUSLE, and an organic solid load was estimated as five percent of the total solids load. As with the impaired streams, only the sediment load from the riparian zone within the watershed was used in the calculation. Owing to differences in stream length between the impaired segments and the reference stream, the target sediment load estimate for each impaired segment was adjusted to compensate for differences between riparian areas of the impaired segment and its reference. This adjustment was necessary because riparian size influences sediment delivery to the stream.

The recommended total organic solids load in the impaired stream (from both point and nonpoint sources) should not exceed the target end point. The area corrected organic solids load end point for Orndorff Spring Branch was set to 127 pounds per year, and the end point for Lacey Spring Branch was set to 957 pounds per year. To meet the end point goal, the combined point and nonpoint organic solids load to the impaired stream should not exceed the target.

10. Make recommendations for pollutant load allocation and management practices

The recommended organic solids load reduction from the trout farm effluents entering Orndorff Spring Branch and Lacey Spring Branch was 98 percent for both trout facilities. Reductions from zero percent (for roads) to 53 percent (for pastureland) were recommended for the nonpoint sources on Lacey Spring Branch. To achieve these goals, point source and nonpoint source management practices were recommended. Point source management practices were suggested that increase the effectiveness of capturing and removing solids from the effluent (e.g., more frequent cleaning of sediment traps, installation of a settling basin, and land application of the removed solids). Suggested nonpoint source management practices included installing vegetative buffer strips of grass and canopy along the impaired segment and fencing livestock away from the stream.

Discussion

TMDL reports were developed based on approaches and methods described in this paper. These reports have been submitted to the EPA for final approval. A National Research Council report that assessed the TMDL program recommended that the uncertainties of the TMDL calculations be recognized and addressed within the report, in ways other than an arbitrarily set margin of safety factor (NRC 2001). In this TMDL report, a margin of safety of five percent of the established target load for the impaired stream was used following the current TMDL guidelines, but the submitted report also contained information about the uncertainties inherit in the TMDL study. The outlined uncertainties are summarized below.

Uncertainty in Target Selection

There is significant uncertainty in the biomonitoring and organic solids load target selection. It is impossible to select a comparable reference site that exactly matches the targeted stream characteristics. The headwaters of the impaired streams are springs that have unique water chemistry. There are also significant differences between the reference streams and the listed impaired segments in terms of the watershed sizes, physical characteristics, and flow rates. In summary, sufficient data are lacking to describe the composition of the benthic community in the listed impaired segments prior to the introduction of human activity, presuming that this is the target to be sought.

Uncertainty in Effluent Monitoring

One advantage of biomonitoring is that the benthic community integrates acute and chronic impacts to the stream, whereas chemical monitoring provides only a "snap shot" of the water quality. The water sample schedule used in the TMDL study was designed to capture episodic peaks during daily routine operations at the facilities (e.g., feeding and harvesting fish; cleaning of sediment traps). Monitoring however, did not take place during the large-scale clean-out of the settling area that occurs only once or twice a year. The water sample collection for the TMDL study therefore missed events that were not missed by the benthic community.

Uncertainty of Organic Content

Volatile solids were not measured in the spring water, effluent, and stream samples. Instead the organic solids loads were determined from estimates of organic content. It is likely the estimates do not represent the true organic content, although the estimates are believed to provide an accurate indication of the amount of organic material. For example, the 60 percent organic content estimated for the trout farm effluent is believed to be lower than the true amount. However, the percentage is still high and much larger than the estimated 5 percent organic content attributed to the nonpoint sources.

Uncertainty of BMP Effectiveness

Research by Boardman et al. (1998) was used in calculating the reduction loads for many of the BMPs for the trout facilities. In their report, they expressed caution in expecting similar results from full-scale applications as seen in their laboratory scale experiments and pilot plant studies. The actual success of the BMPs will depend on the conditions at the trout farm, including the flow, TSS concentration, temperature, wind, and other factors.

The submitted TMDL report stresses that implementation plans can be developed that will improve water quality. However, implementation decisions based on the conclusions of the TMDL report should recognize and accommodate the uncertainties in the analyses.

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